How Can BCI-controlled Hand Prosthetics Improve the Lives of People Without Hands?

Jodie Lechtenberg

Theodor

This is Theodor. He loves being outside to climb rocks or go swimming in the lake.

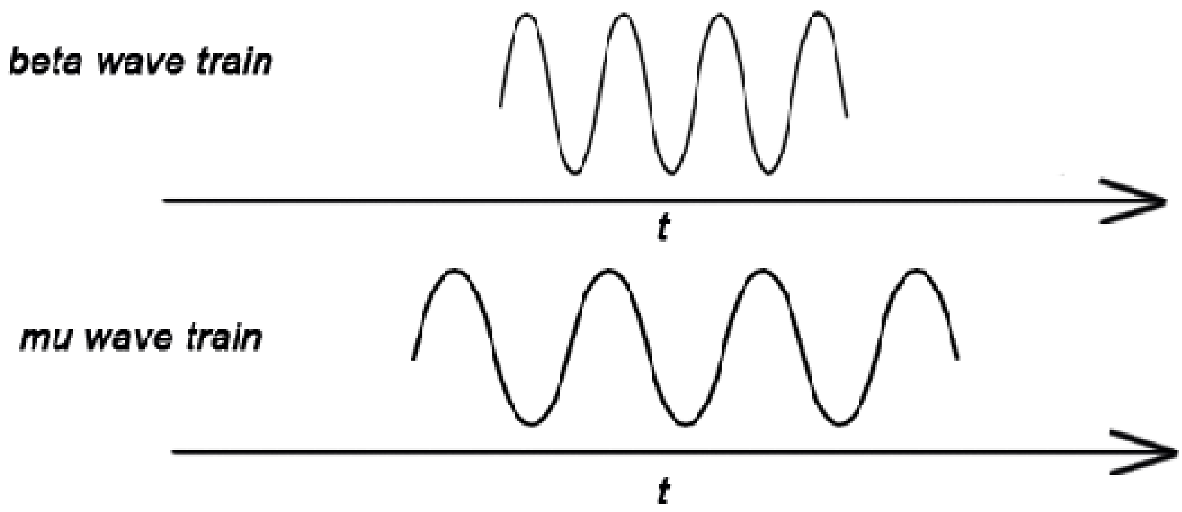
But unfortunately, he lost his hand to cancer and isn't able to do his favorite activities anymore. He first tried normal prosthetics but that didn't work because the movements his fingers could perform were limited.

So, his doctor recommended that he could try BCI-controlled prosthetics. These would allow him to gain more control over his fingers/hand movements and better mimic his natural capabilities.

How does this work?

The process begins with acquiring the brain signals. This is done by using electroencephalography (EEG). EEG involves placing electrodes on the scalp to detect the electrical activity in the brain: Neurons in the brain communicate through electrical impulses. When neurons fire (to transmit information, to help the brain and body communicate), they create small electrical currents. EEG electrodes pick up these signals as they travel through the scalp and skull.

The raw brain signals collected from EEG are then processed. The first step is to remove any unwanted signals caused by e.g. blinking or external interference.



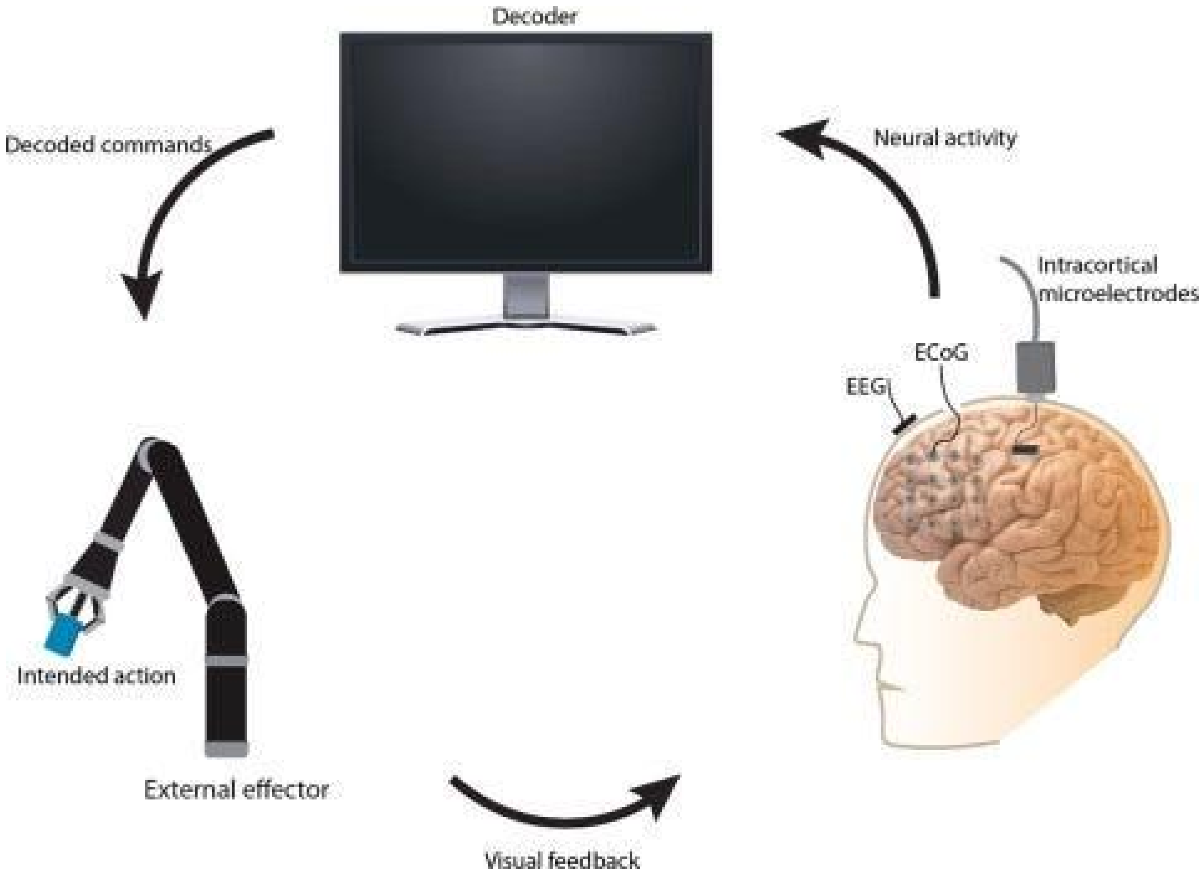
mu wave frequency

The primary step involves applying a bandpass filter. The purpose of this filter is to isolate the frequency bands that are relevant for intention. Common frequency bands for hand prosthetics include the mu waves (8 – 13 Hz), which are similar to alpha waves.

Machine learning tools, specifically Convolutional Neural Networks (CNN), are trained to recognize patterns and relationships within the preprocessed brain signal data. In a learning phase, people do different tasks, teaching this system how the brain behaves when we think about various movements, like opening or closing a hand or moving fingers.

These brain signals are then turned into specific instructions for the prosthetic hand. Each thought about moving triggers an action in the prosthetic hand, for instance, grabbing something, letting go, or moving fingers individually.

After this translation, these instructions are sent to the prosthetic hand's "muscles" called actuators (BCI output). When the person tries to move their own muscles, they produce tiny electrical signals (EMG signals). Electrodes catch these signals by sensing the small electrical changes caused by these muscle movements:



Theodor's prosthetic hand is practically getting messages directly from his thoughts and muscle movements!

As weeks passed, Theodor could feel significant change, not just in the movements of his bionic hand but also in how he felt all in all.

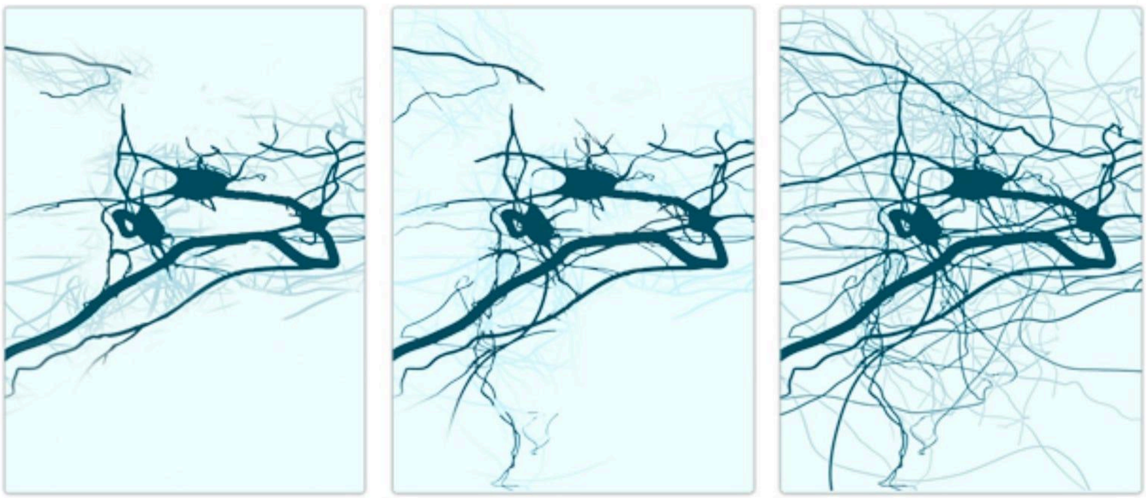
"Why am I feeling better Doctor?"

His brain adapted to the new reality of controlling his prosthetic hand, which is called **Neuroplasticity**.

How does this work though?

Inside our brain, we have billions of tiny cells called neurons. These neurons communicate with each other through connections called synapses.

When we do something repeatedly or focus on a particular skill or thought, the neurons involved in that activity become more active. This increased activity strengthens the connections between these neurons and also forms new ones.



The synapses between neurons are not fixed. They can change based on our experiences and activities. When these neurons are frequently active, the synapses between them undergo structural and chemical changes, which e.g. can lead to Theodor behaving differently than before having a hand prosthetic.

Current Challenges

When Theodor uses a prosthetic hand controlled by his thoughts, there's a challenge.

Getting the brain signals just right can be a bit tricky.

Here's why:

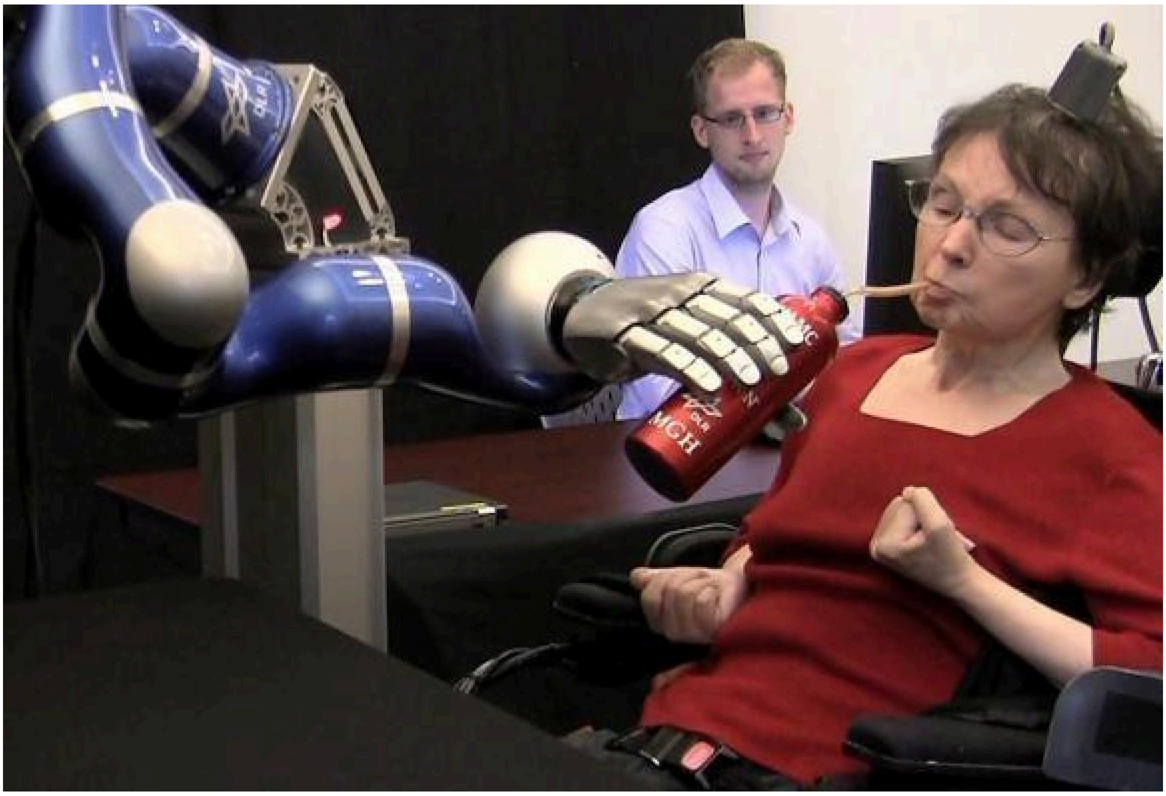
The electrodes on the head need to be in perfect spots to understand the signals. If the person controlling the hand gets tired, the signals might not be clear. Also, our brain changes over time, making it a bit of a moving target.

Now, why does this matter?

If we don't get the signals exactly right, the prosthetic hand might not do what the person wants. It could move in ways they didn't mean, or it might not work smoothly.

But, good news! Scientists are working on making this better. They're figuring out ways to get more precise signals by improving how the electrodes are designed.

Prosthetic Design



When designing artificial limbs, it's important to consider these individual brain differences.

Imagine Theodor and his friend Mike who have both lost their left hands. While both share the same basic need for a left-hand prosthetic, the design would differ based on the specific neural patterns of each person.

But why would they be different from each other?

One distinction lies in the motor cortex. The motor cortex is often depicted as a somatotopic map. The prosthetic is designed to mirror the organization of this map, which means that the prosthetic hand is programmed to respond to neural signals in a way that corresponds to the brain's natural mapping of body parts. For example, if the hands and fingers occupy a large portion of the motor cortex, the prosthetic is configured to interpret signals related to hand and finger movements with lots of precision.

This optimization results in more natural and intuitive movement. Users can control the prosthetic hand in a way that feels instinctive, as the prosthetic's responses align with the brain's natural representation of body parts.

Future Directions / Challenges

Research in brain-computer interfaces for controlling prosthetics is advancing, but it faces several challenges and has exciting future directions.

Scientists and engineers are working on developing advanced electrode technologies, decoding methods, and neural pathway bridging to unlock the full potential.

One of the key challenges is the need to address BCI inefficiency and speed of learning, which may be improved by using multimodal or multi-stage BCI approaches.

Despite these challenges, the potential relevance of BCI is expanding, presenting promising opportunities for the future.

Ending

After losing his hand due to cancer, his doctor proposed to try out a BCI-controlled hand prosthetic. At first, he had some problems using it but with time passing his neurons formed new connections improving the quality of natural movements with his hand.

As Mike's birthday was nearing, Theodor got his dear friend this special prosthetic.

And who knows, maybe one day when technology has advanced, they'll both be able to climb rocks and swim in their favorite lakes again,

thanks to BCI-controlled hand prosthetics!